Large Area Instant Crack Detection And Identification Using Magnetic Carpet Probe

Yushi Sun, Tianhe Ouyang
Innovative Materials Testing Technologies, Inc.

FAA Award No. DTFACT-04-C-00013

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 APR 2006**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Large Area Instant Crack Detection And Identification Using Magnetic Carpet Probe**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Mechanical & Aerospace Engineering Department and Materials Science & Innovative Materials Testing Technologies, Inc.**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**27**	

Acknowledgements

The authors would like to express their great thanks and appreciation to

Cu Nguyen, FAA W.J. Hughes Technical Center;

Dr. Mike D. Bode and Dr. Floyd W. Spencer, FAA AANC at Sandia Labs

for their guidance, instructions and help provided during the entire project period.

Motivations (1)

1. FAA forecasts that commercial aircraft operations will continue to increase by 3 to 5 percent per year over the next decade.

2. Government and industry have agreed to use enhanced inspections for certain high-energy rotating engine components.

3. A number new NDT methods and R&D projects are currently going on towards an optimal solution of this problem.

Motivations (2)

Current NDT techniques do not meet the requirements for wide area inspection of engine disc:

- **EC Pencil probe – very low inspection speed and significant noise;**
- **Penetration method – low speed and low sensitivity;**
- **Magnetic particle – does not work for non-ferromagnetic materials.**

Objectives and Requirements

Development of Magnetic Carpet Probe (MCP) Technology For Rapid Large Area Engine Inspections.

1. Capable of detection of fine surface cracks, as small as 0.020”, on titanium engine disc;
2. Ten times faster then any of the traditional inspection method;
3. Flexible to conform to curved surfaces;
4. Robust and reliable;
5. Simple to use and low cost.

Why Magnetic Carpet Probe?

1. Absolute static inspection:
   a. No mechanical noise – ensuring high sensitivity;
   b. Electronic and magnetic scan – ensuring high speed, or instant, inspection of large area;
   c. No mechanic parts/components, a pure electronic device – ensuring
      - Simplicity, robustness, light weight and reliability;
      - Easy in use an low cost.
2. Thin and flexible 2-Dimensional sensor array – providing capabilities in
   - Conforming to curved surface;
   - Being attached to inaccessible or difficult accessible areas for heath monitoring;
   - Possibility for future remote control of NDI and heath monitoring through networking and/or wireless techniques.
3. Software controlled call/reject action. Minimum human factor involved.

Foundations for MCP

1. Advances of Flexible Printed Circuit (Flex Circuits) technique allow building very thin, copper traces and spacing in very thin material layer. This enables building a large number of electromagnetic coils, or coil array, in a thin layer structure with reasonable coil size, impedance value and inspection resolution.

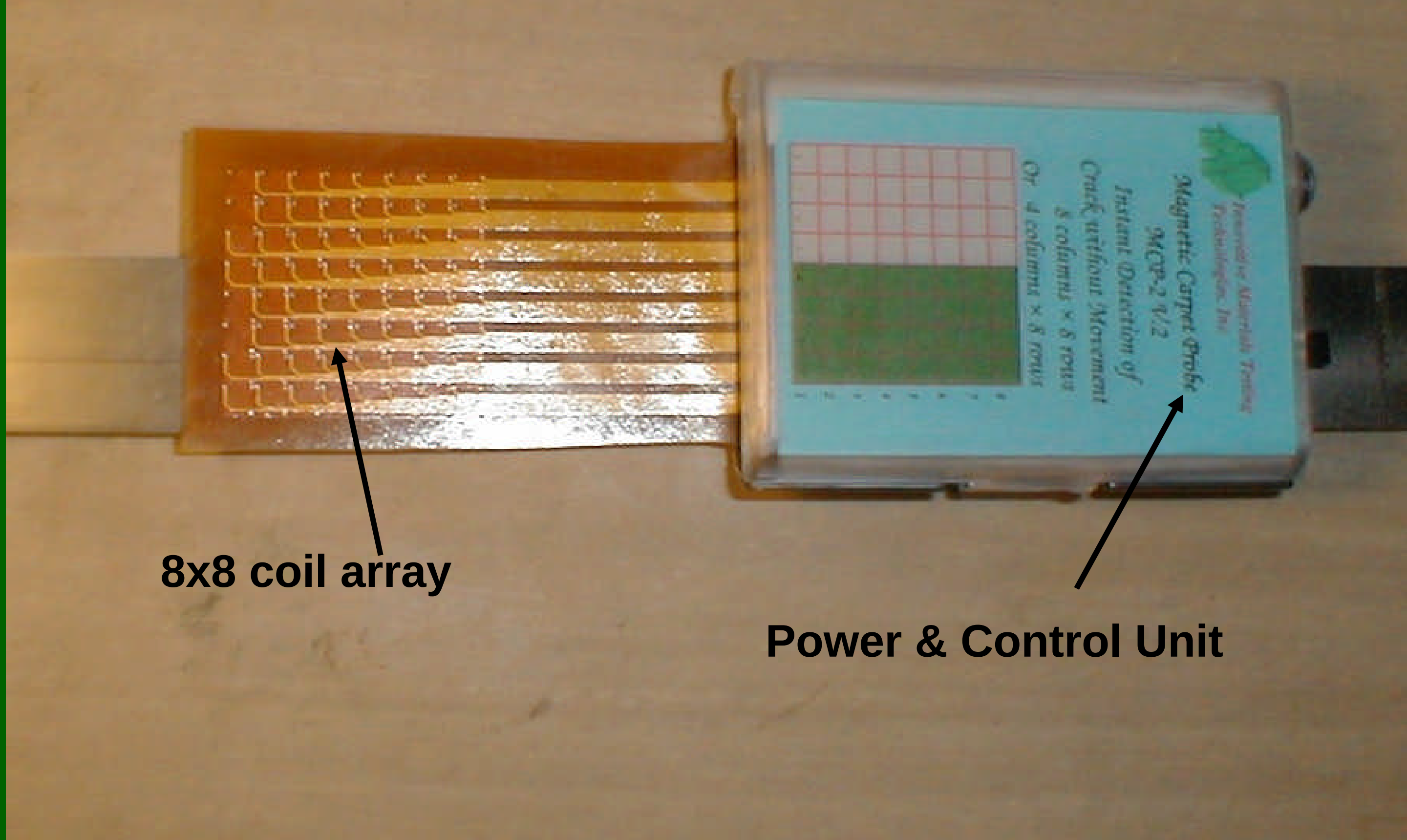
2. Advances in digital electronic devices have enabled complex and high speed electronic and electromagnetic scan over a coil array with a large of elements, or coils, using a very limited number of miniature chips.

Achievement of these two techniques has established the foundation of the MCP technique.

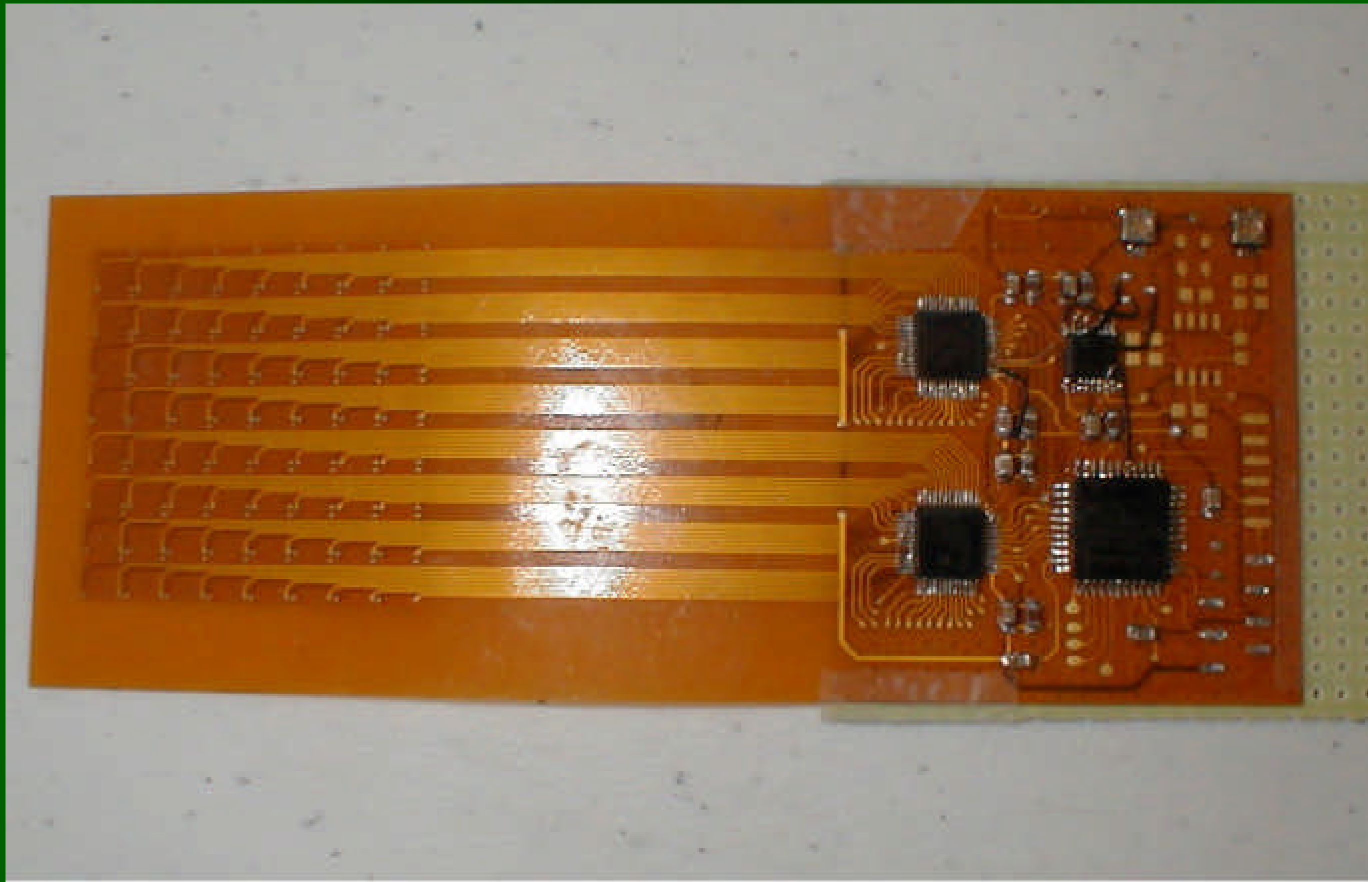
Working Principles of MCP

1. Densely populated 2-D coil elements, coil array, built in flex circuit and covering a wide area of inspection;
2. Connection of each coil element of coil array to an eddy current instrument through multiplexers;
3. Electronic control of high speed electromagnetic scan over the entire area of inspection.
4. Automatic image, crack/corrosion identification, and display.

Magnetic Carpet Probe MCP-1 V2
Photo of Prototype (1)



Magnetic Carpet Probe MCP-1 V2
Photo of Prototype (2)



Magnetic Carpet Probe MCP-1 V2
Photo of Prototype (3)

8×8 coil array covering 1.375” × 1.375” area of Inspection

Six layers Flexible PCB with total thickness of 0.012”

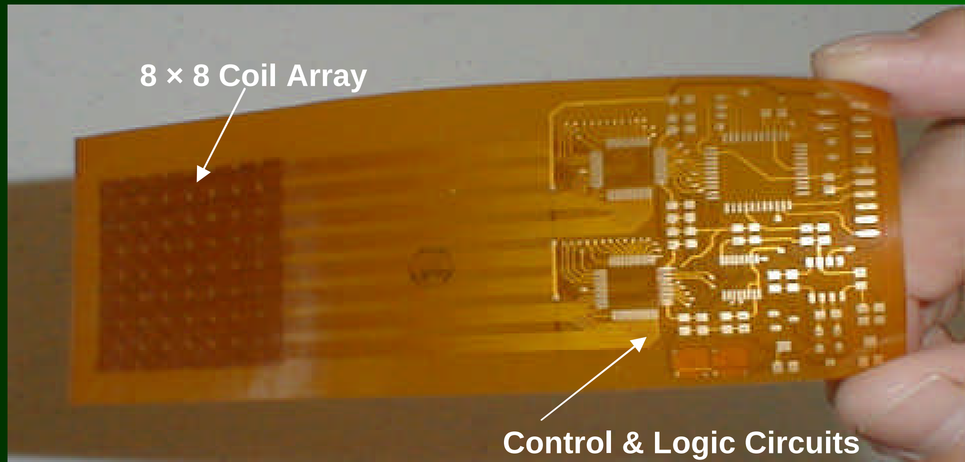
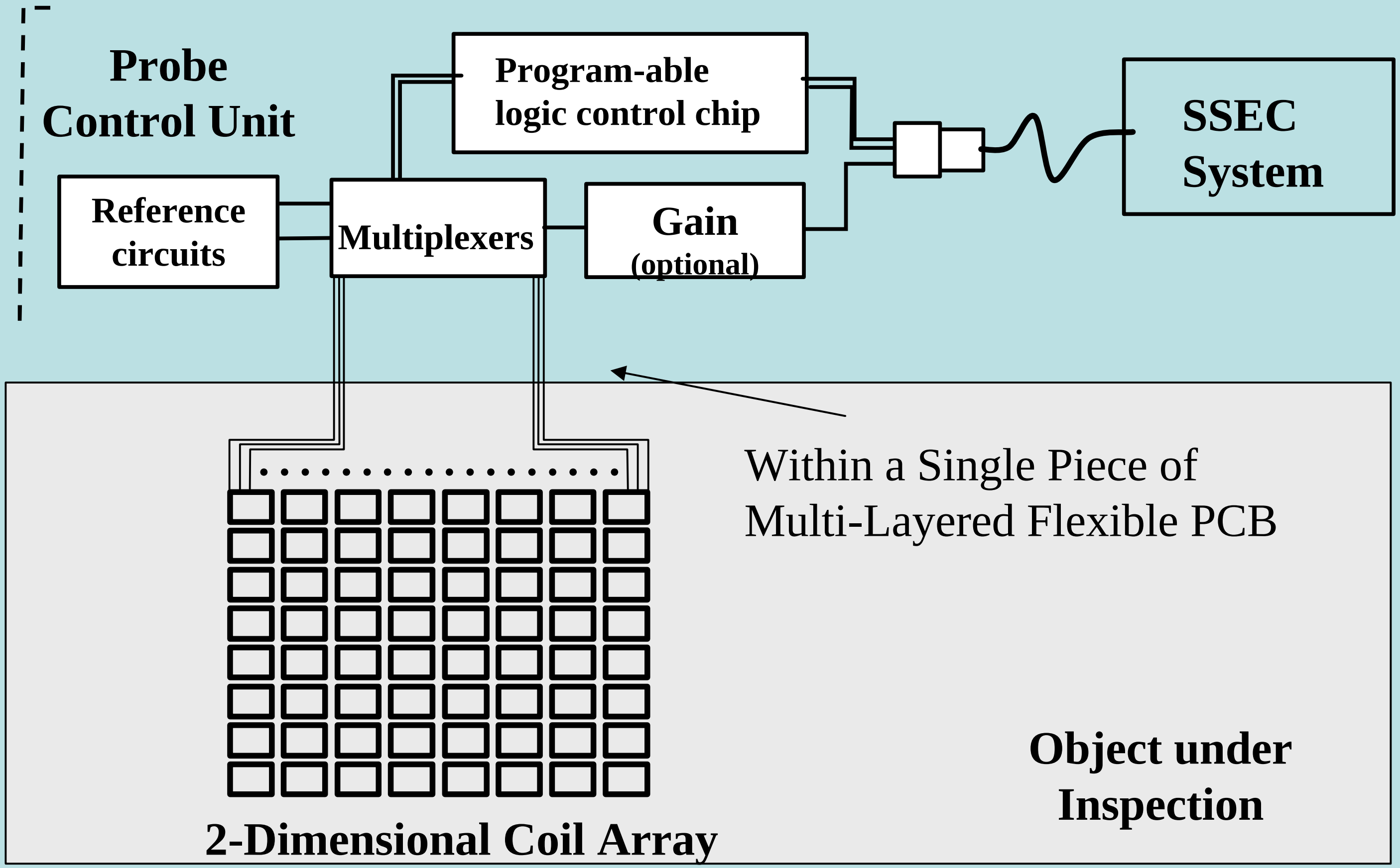


Diagram for Magnetic Carpet Probe, MCP-1 V.2 Working in Differential Mode



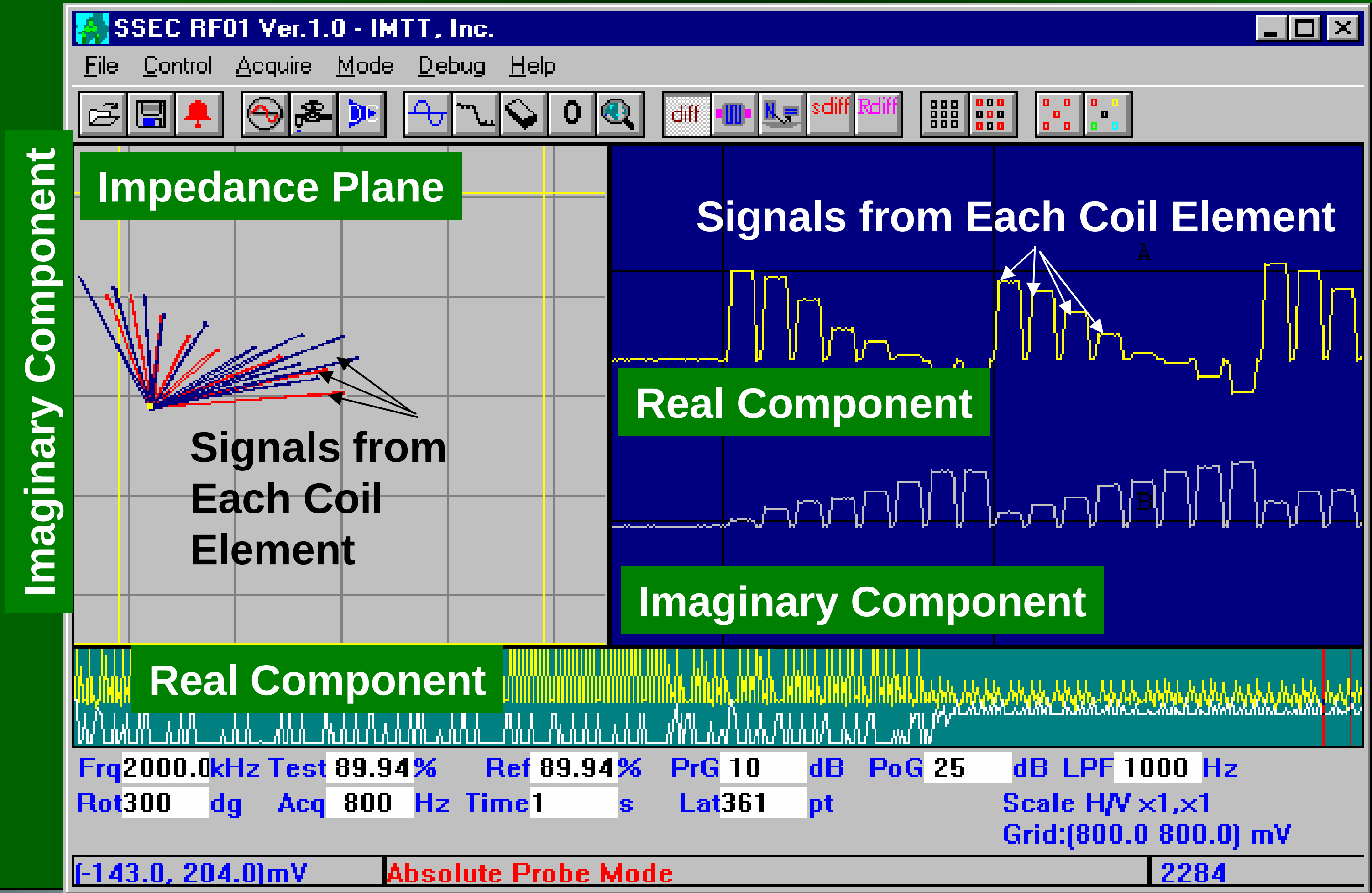
Program-able Logic Control Unit

FPGA or CPLD are typical program-able chips.

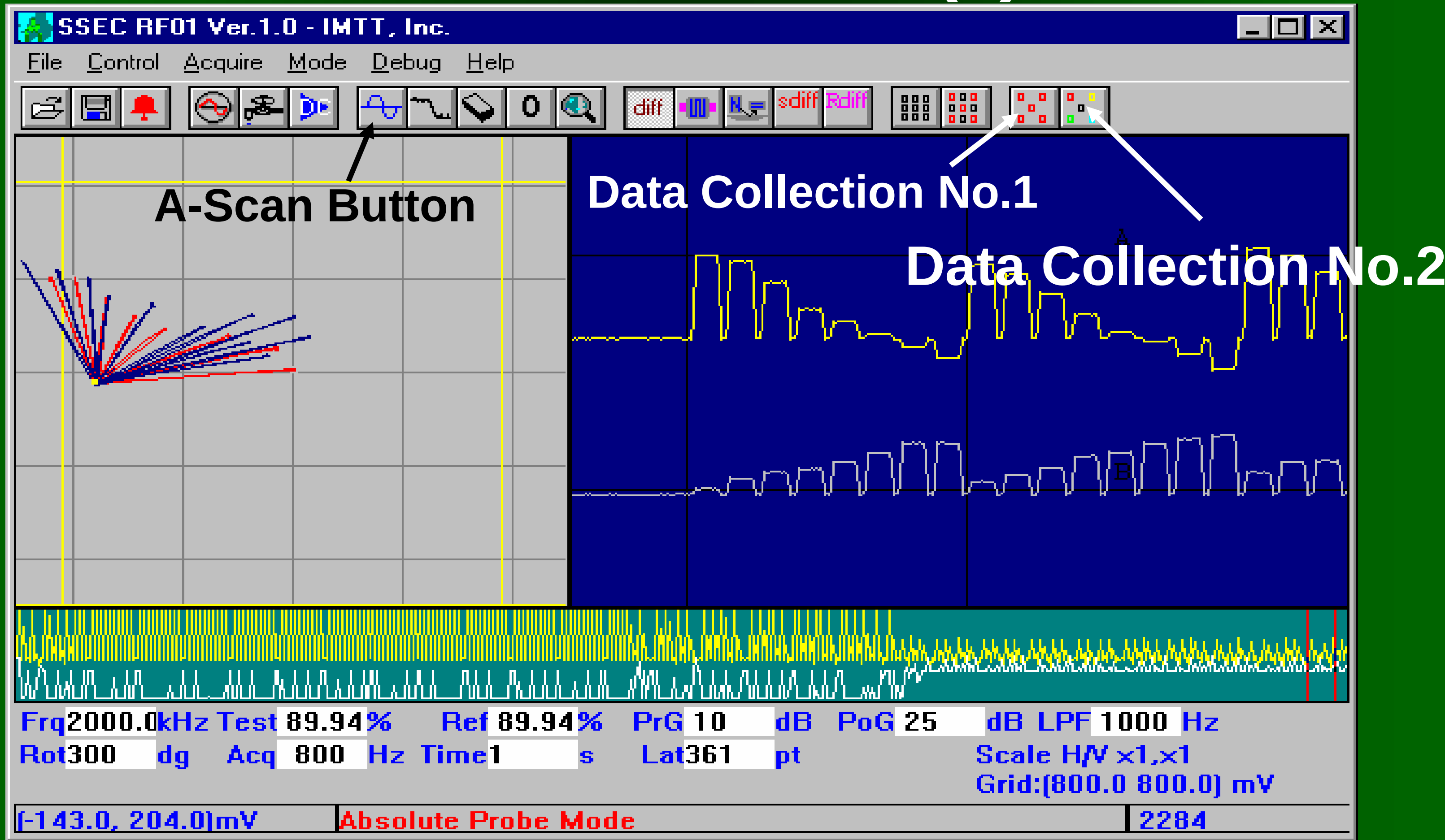
They can be programmed to generate logic control signals we need. These signals include:

1. Multiplexer timing signals for scanning sequence of coils in coil array ;
2. Signals for working in differential mode;
3. Signals for working in nulling mode and selection of null position that appears on the screen;
4. Signals for working in zoom-in mode and selection of the column and row numbers for the zoom-in location. For example, in the test results listed in this report we used only 4 columns and all 8 rows.

Typical Signals: A Copy from the Screen



Test Procedure (1)



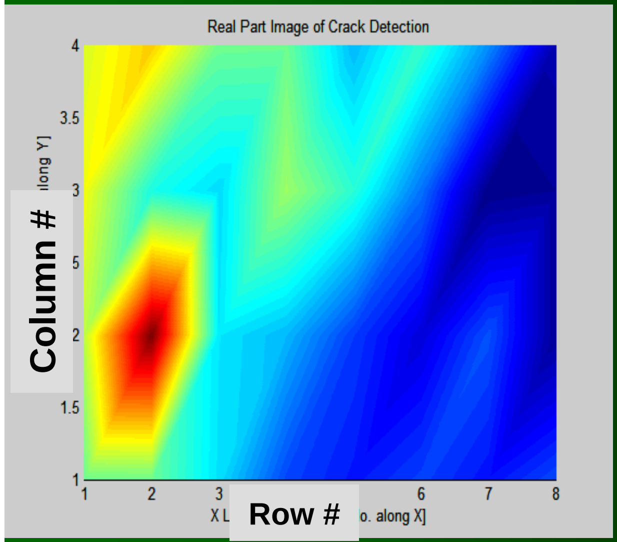
Test Procedure (2)

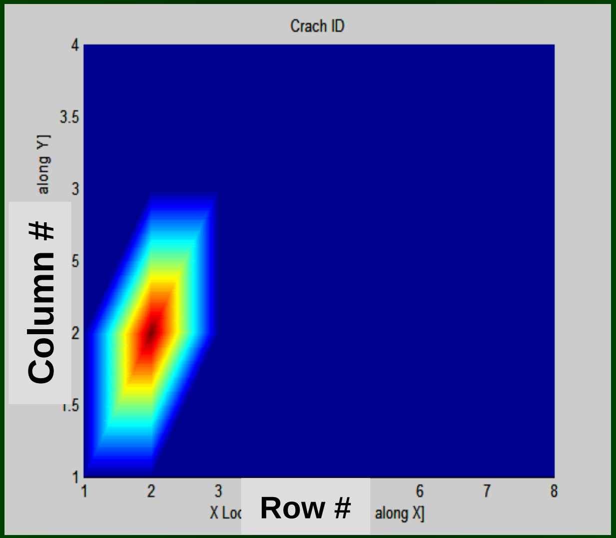
1. Firmly place MCP on a no-crack area;
2. Click "A-Scan" to start a scan & wait for abut 2 seconds;
3. Click "Data Collection No. 1". No-crack data are collected and processed practically in no time;

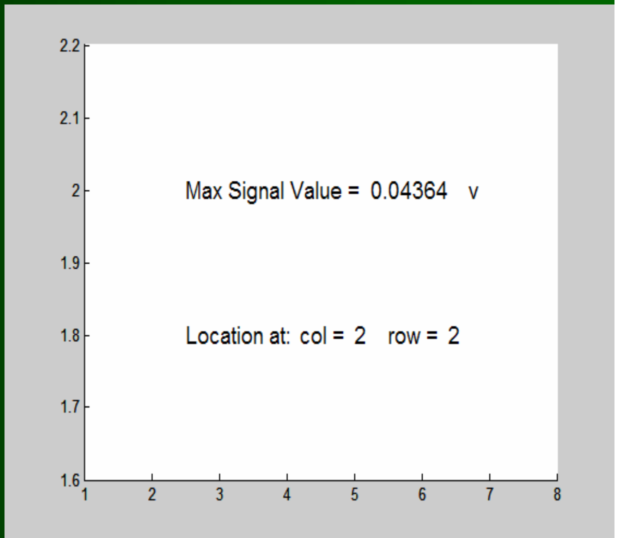
Note: we need to do 1, 2, and 3 only once per an inspection.

4. Firmly place MCP on the area of inspection;
5. Click "Date Collection No.2". Crack data are collected and processed practically in no time;
6. All three images appear on the screen in a couple of seconds.

Signal & Information Displays







Display No. 1:

Image of signals obtained from all the sensor coils

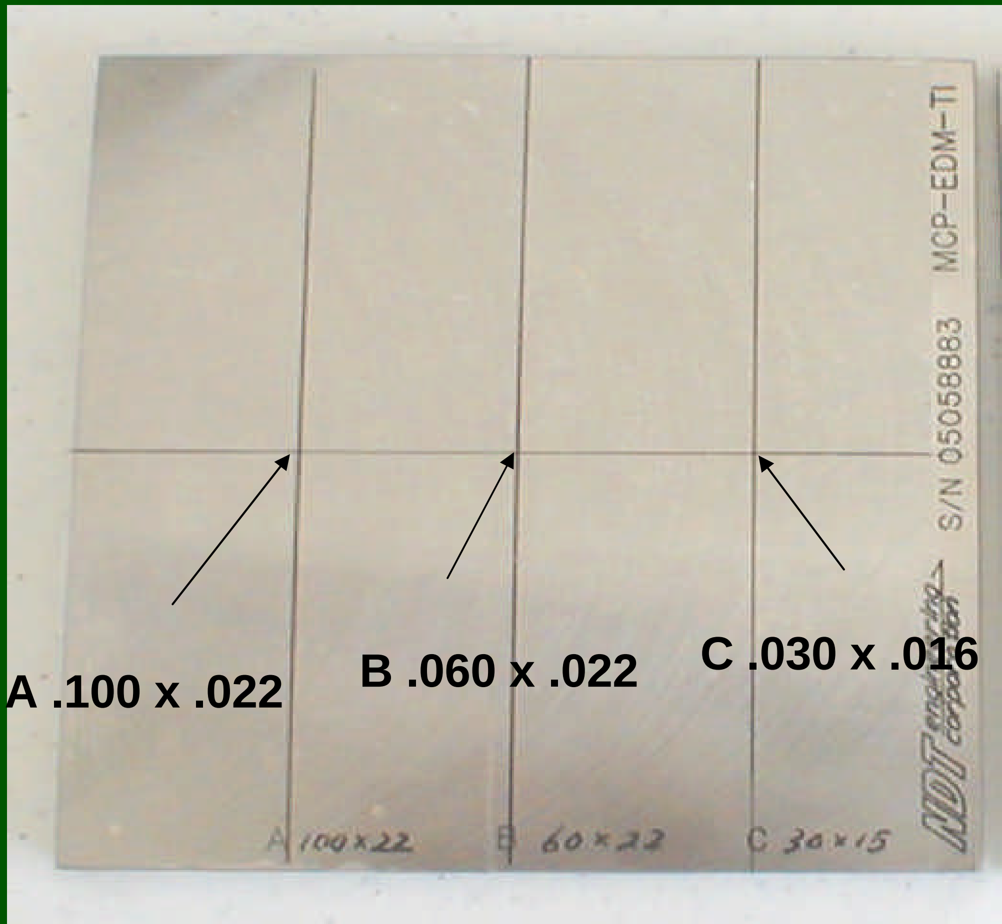
Display No. 2:

Processed image for identification of a crack and its location

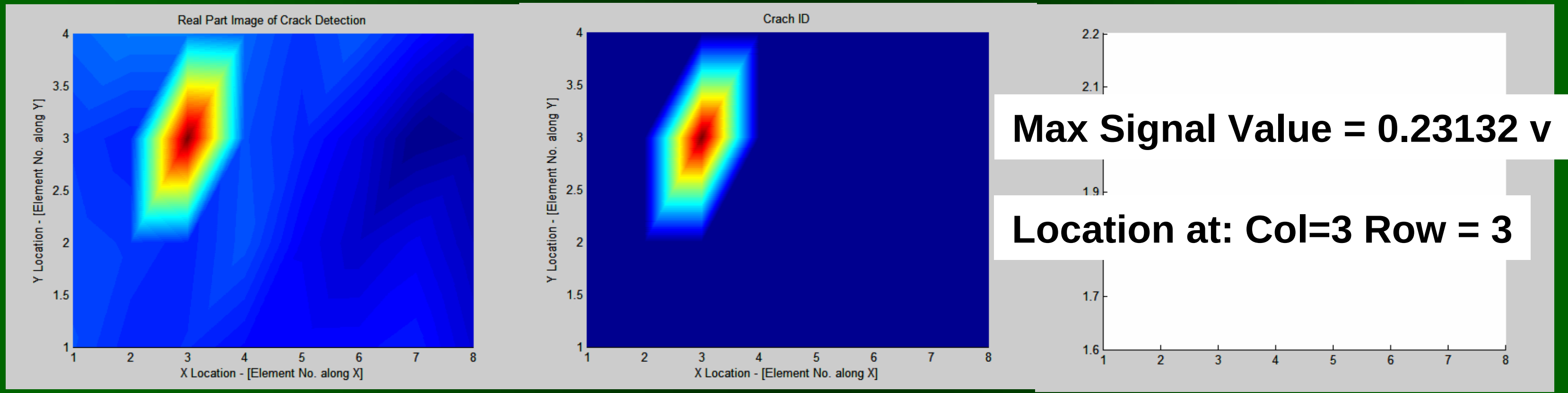
Display No. 3:

Printed information: signal value & crack location

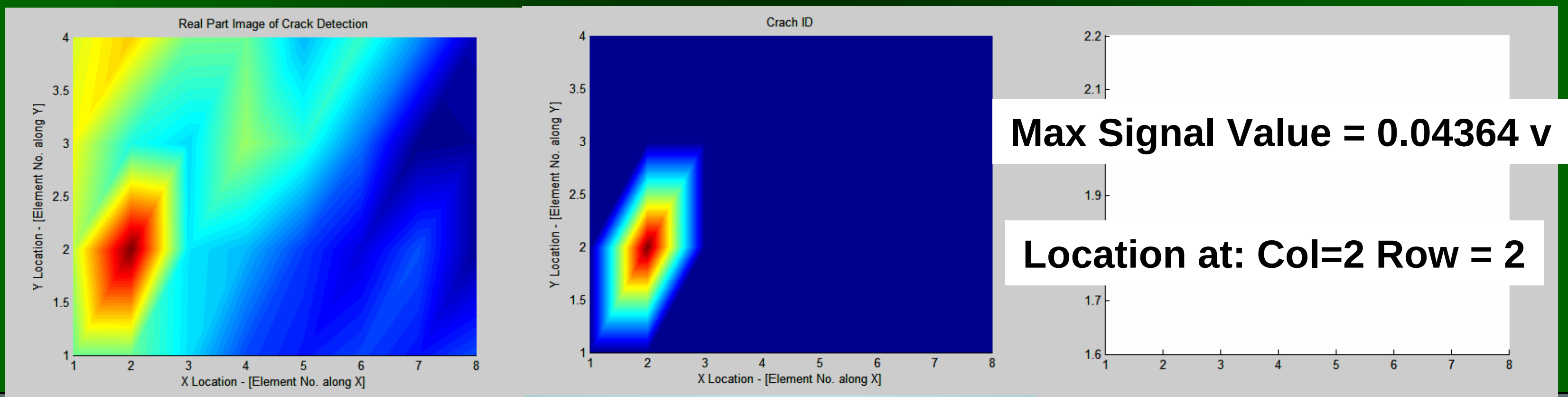
Detecting EDM Notches On A Titanium Standard
(1). Ti EDM Notch Standard



Notch B: 0.060” x 0.022”



Notch C: 0.030” x 0.016”

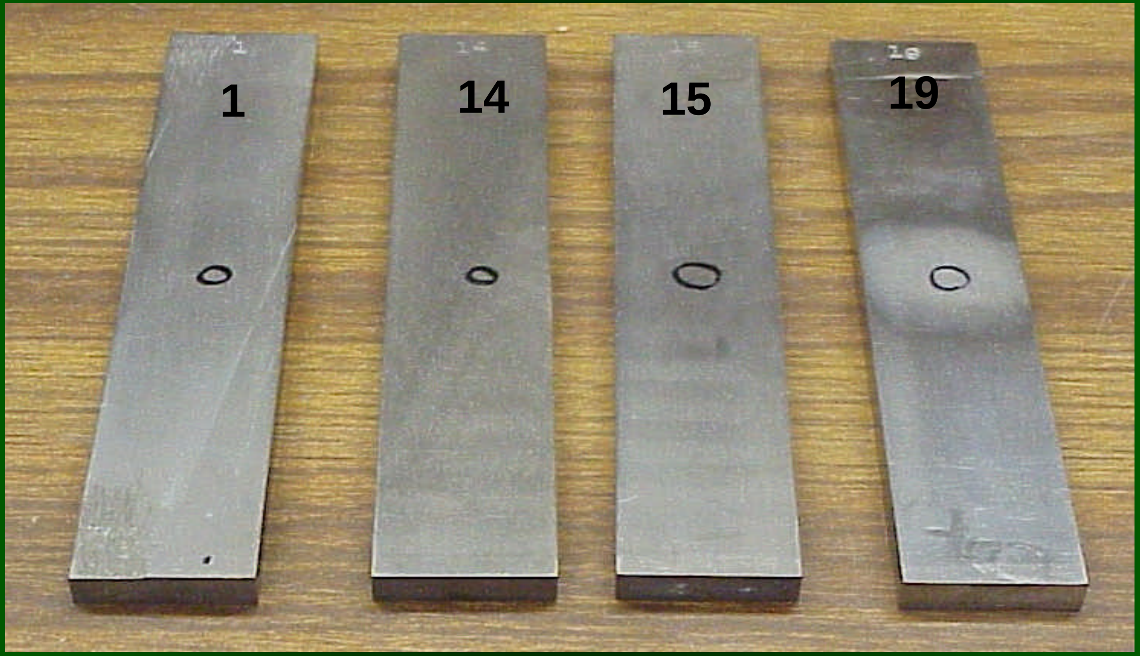


Testing Real Cracks On Titanium Standards

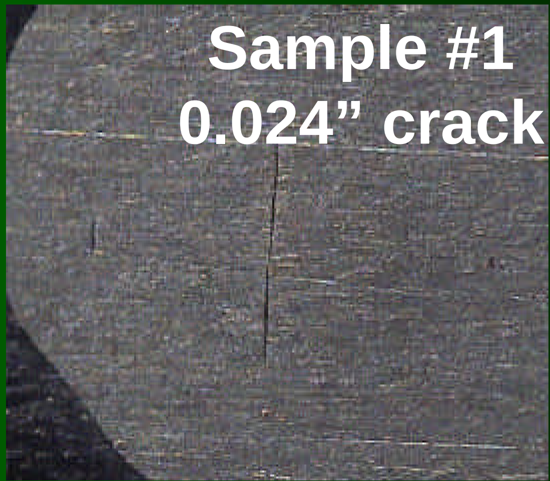
Provided by Mike Bode, FAA AANC, Sandia

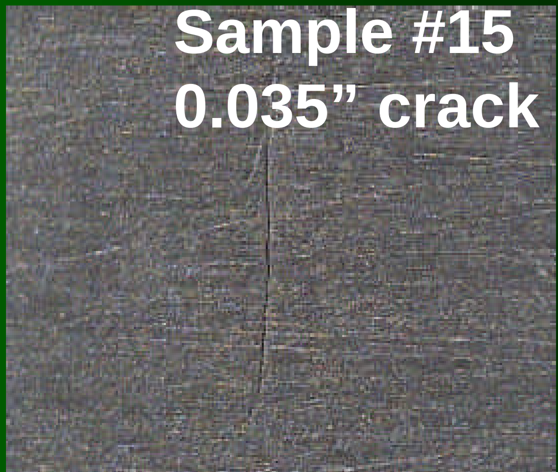
(1). Four Standards

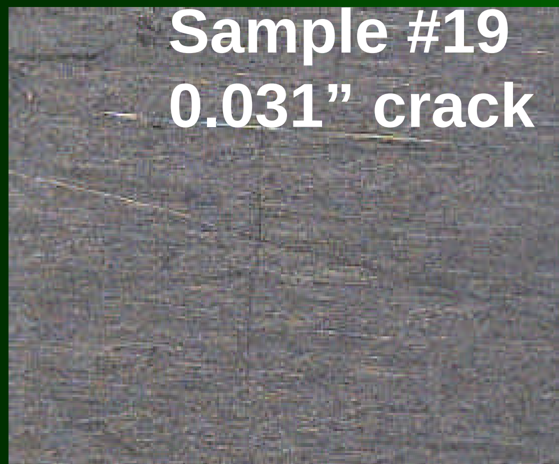
6.0” × 1.0” × 0.25” Titanium Crack Sample



(2). Crack Photos Sizes

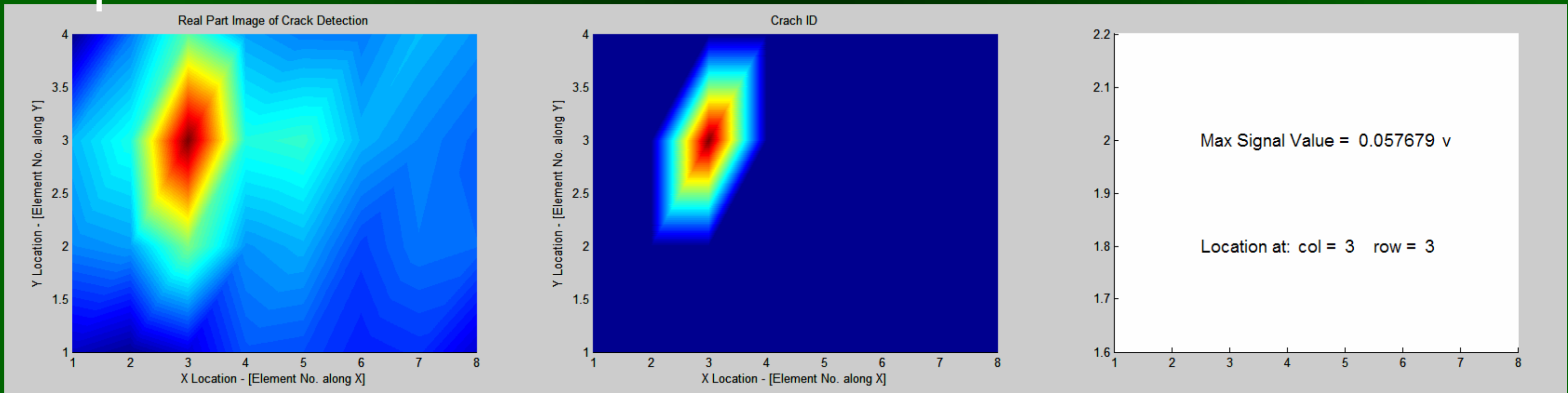




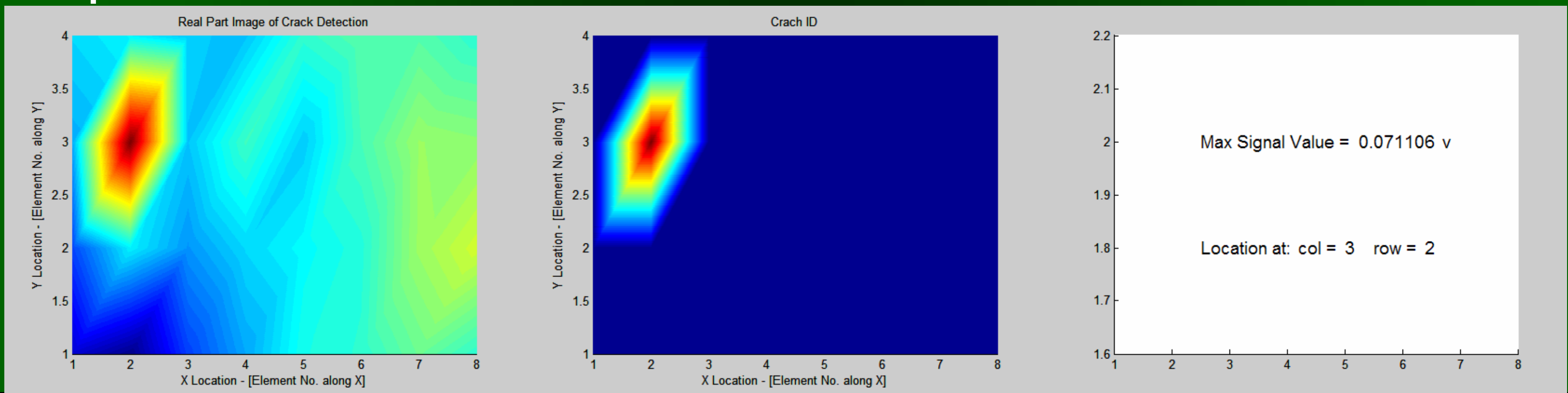


(3). Testing Fatigue Crack Standard (1)

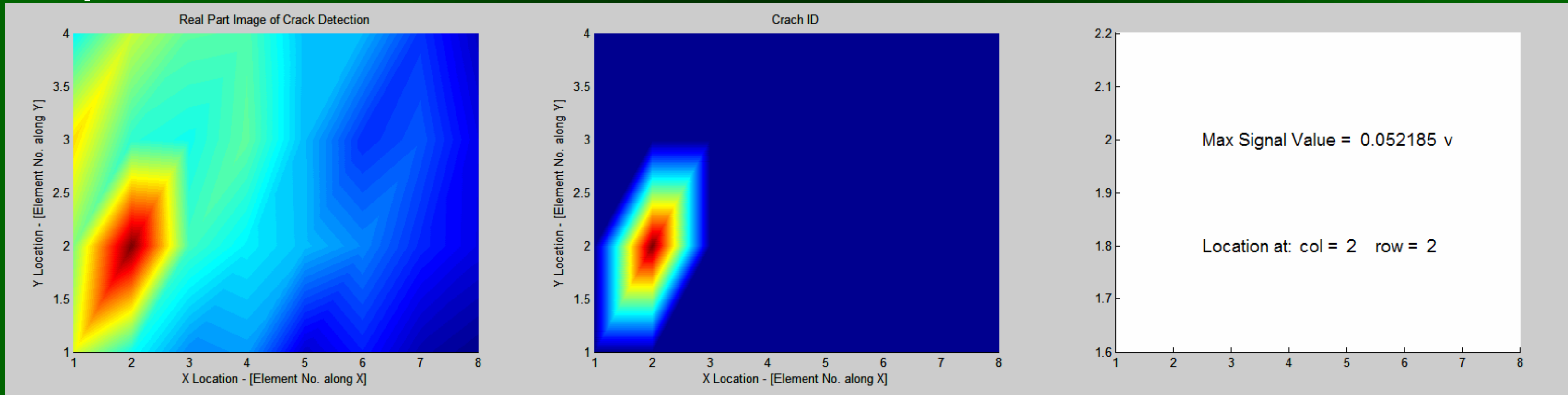
Specimen #1



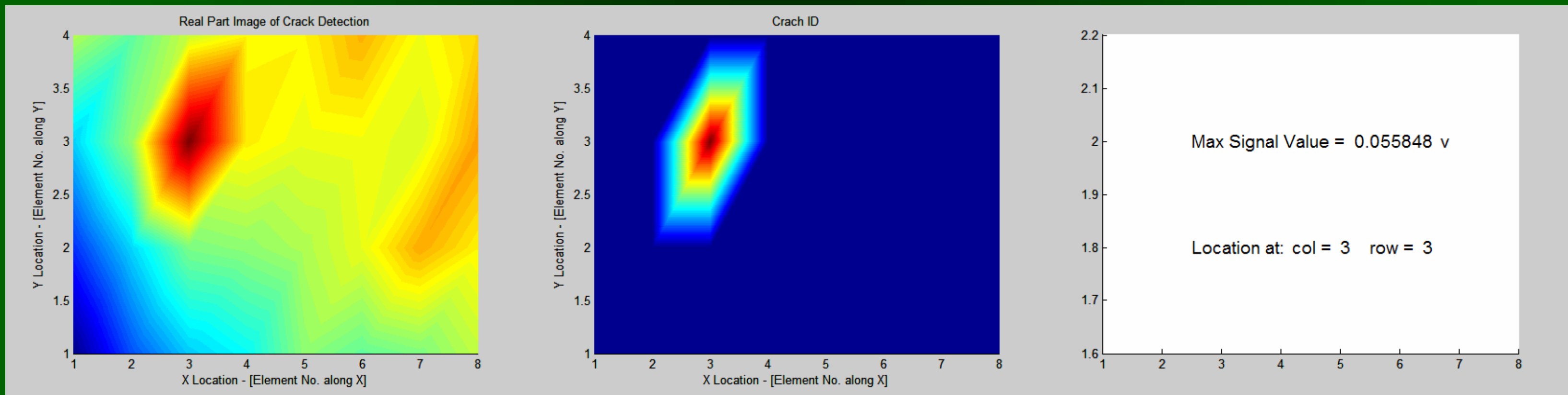
Specimen #14



Specimen #19

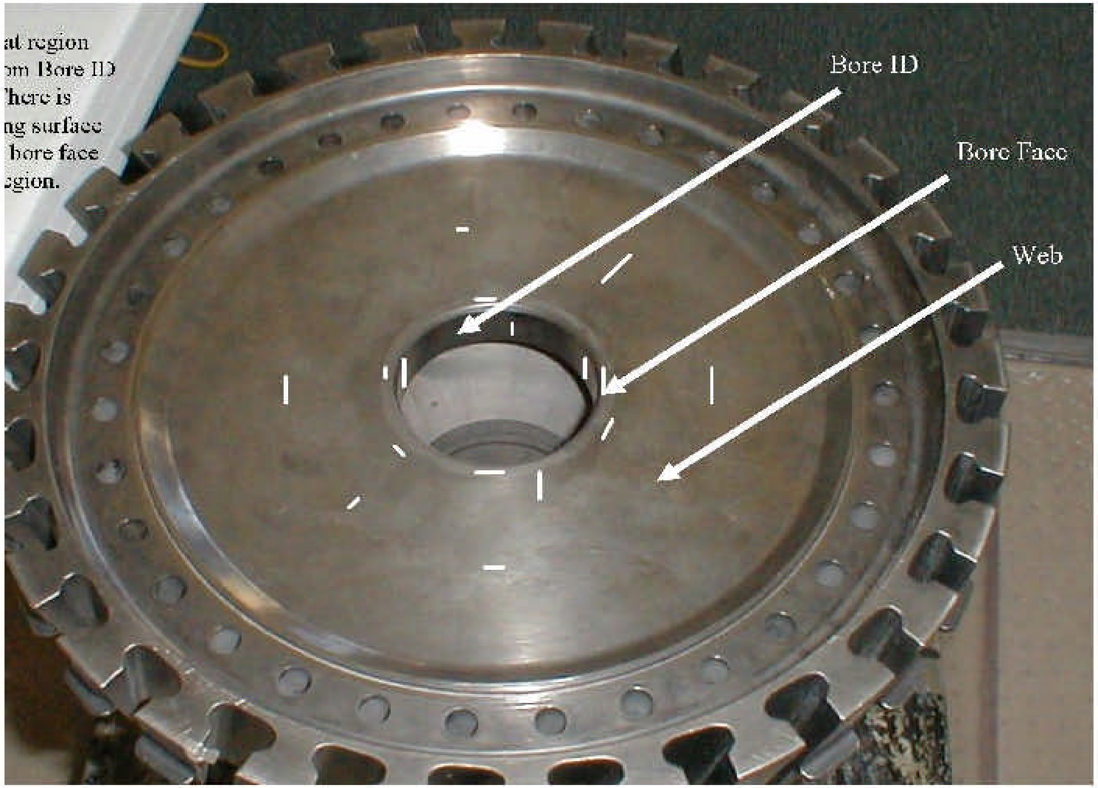


Specimen #15

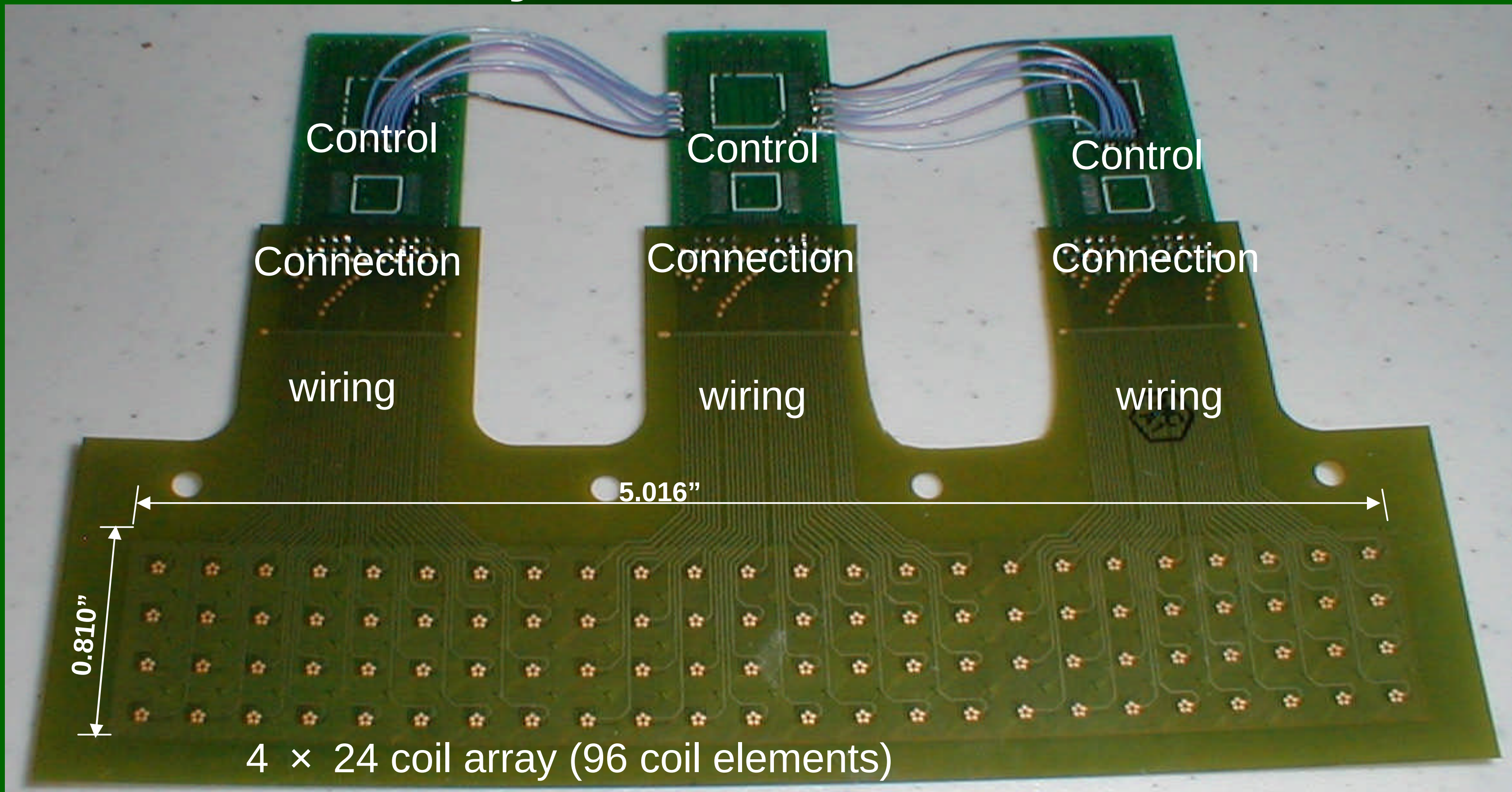


Planned Testing EDM Notches On Engine Bore ID

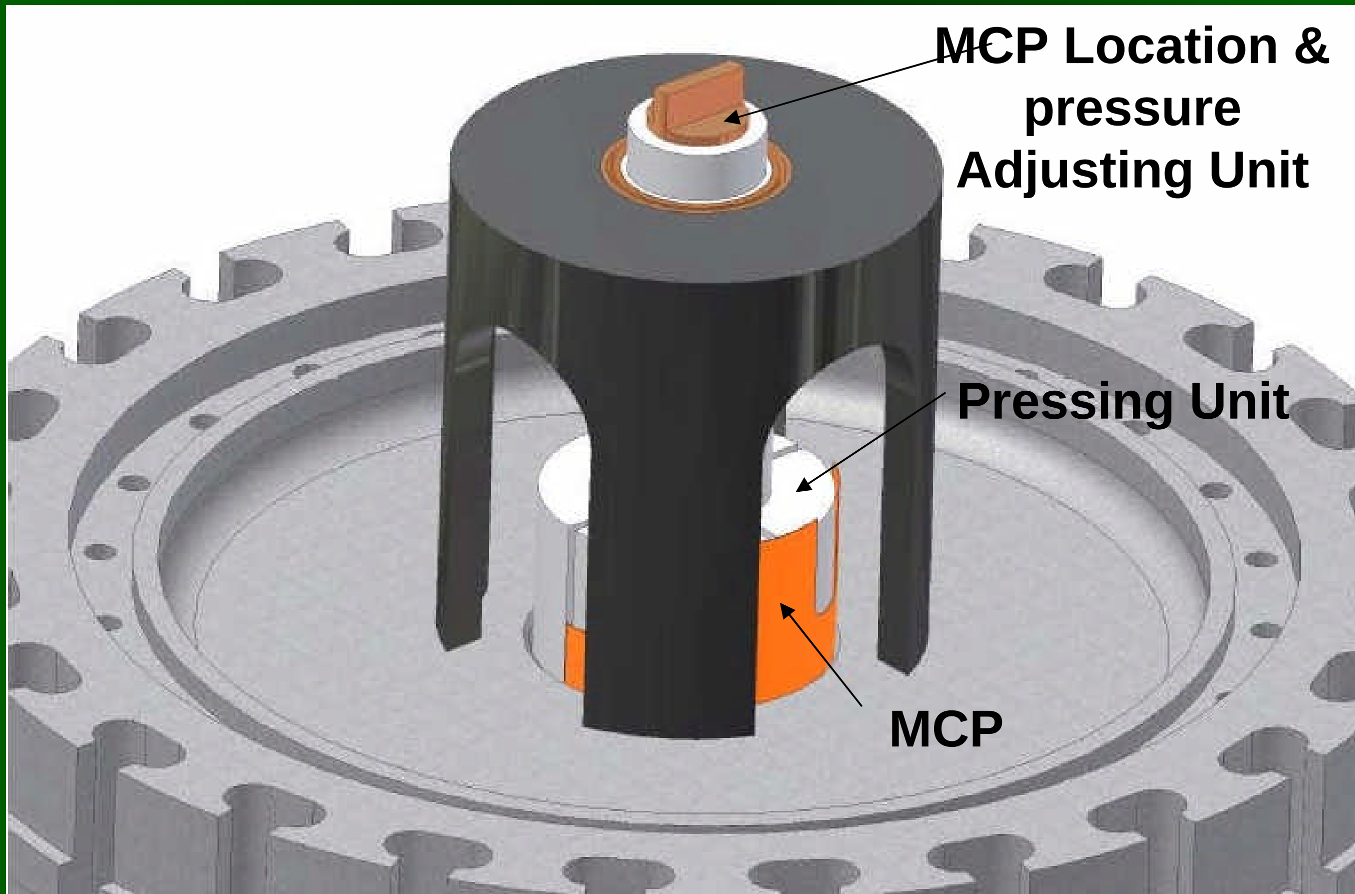
Provided by Mike Bode, FAA AANC, Sandia



Prototype MCP-1 V.5
A 10 layer and 96 element Circuit



Designed Fixture Placing and Holding MCP At Bore ID Location



Conclusions

1. A new NDI method for large-area and instant inspection of engine disc, MCP Technique, has been developed. A number of prototypes have been developed.
2. Test results have shown it is promising. The unique features include:
   - No mechanic noise, high sensitivity;
   - High speed large area inspection;
   - Simplicity, robustness, and low cost;
   - Conformable to curve surfaces;
   - Attachable to non-accessible areas for possible health monitoring;
   - Software controlled call/reject actions, minimum human factor.
3. Future work – apply the technique in read engine disc applications